THE DEVELOPMENTS
by the
General Electric Company
of
RADIO RECEIVING TUBES

CONFIDENTIAL

Not for Publication Purposes

March 1, 1929

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INTRODUCTORY

Edison Effect

In 1883, Thomas A. Edison discovered that if an independent wire or plate were placed between the legs of the (carbon) filament in a lamp, operated on direct current, a small current would flow from this wire or plate, if it were connected to the positive terminal of the lamp. This phenomenon was called the "Edison Effect", for which a patent was issued to him in 1883.

Edison had noticed that a glow frequently appeared in the bulb when current was passed through the filament while the lamp was being exhausted. It seemed strange that this should occur as it appeared that it was probably due to current flowing through the rarefied gases in the bulb, even though there was apparently a much lower resistance path for the current through the filament itself. In order to determine this he made several experimental lamps, some with a wire and others with a plate mounted between the filament legs, connecting the plate through a galvanometer to one terminal of the lamp outside the bulb. A small current flowed only when the galvanometer was connected to the positive terminal.

Fleming Valve

Nothing practical was done with this discovery until 1905 when Prof. J. A. Fleming worked out his idea of using it for its rectifying effect on alternating current as a detector of radio signals in place of the "coherer" used by Marconi.

Audion

Dr. Lee DeForest made a notable invention, about 1906, by introducing a third element, the grid, into a two element tube. In DeForest's three element tube, which he called an "Audion", the grid is placed between the filament and plate. Slight variations in voltage impressed on the grid, produce relatively much greater variations in the plate current than if such voltage variations were placed directly on the plate.

Both the Fleming valve and the DeForest audion were limited in the voltage which could be impressed on the plate without causing considerable "ionization" which limits the useful capacity of a tube. For example, the useful capacity of the audion did not exceed six milliwatts (six-thousandths of a watt). Through the inventions of Dr. Langmuir, three element tubes have been made with useful capacities as high as 100 kilowatts, which is over sixteen millions times that of the audion. It was Dr. Langmuir's inventions which made broadcasting possible.

DR. LANGMUIR'S WORK

High Vacuum Investigation

We are used to the idea of electric current flowing in a conductor. When an electric current flows across a gap or open space, such as a gap between the two electrodes in a tube, we naturally ask what it is through which the current flows? The answer to this question which satisfied most scientists, until Dr. Langmuir showed otherwise, was that the current flowed through an ionized gas; a gaseous conductor. It was thus that both Dr. DeForest and Dr. Fleming explained that current would pass through their tubes.

The gas was regarded as essential to the action and up to the time when Dr. Langmuir's invention was announced, and even for a while after, those who had studied the matter most carefully were of the opinion that a perfect vacuum would be a perfect insulator; that no current would flow through it.

Among the problems on which the Research Laboratory at Schenectady were working, when Dr. Langmuir joined their staff in 1909, was the offsetting of drawn tungsten wire. Dr. Langmuir conceived the idea that this might be due to gaseous impurities in the wire, and undertook to apply some of the methods which had been developed in the laboratory for obtaining high vacuum that he might measure the quantities of gas driven out of these wires when heated. He had in mind the statements, which were then common in scientific literature, to the effect that wires in vacuum continued to give off gas almost indefinitely, and that it was practically impossible, by heating or in any other way, to get metals so free from gas that they would not continue to give it off.

Dr. Langmuir did not solve the offsetting difficulty. However, he continued the researches on gases at low pressure and advanced still further the already extraordinarily developed vacuum technique of the Laboratories.

Electrons

From 1889 to 1913, Prof. J. J. Thomson, a very distinguished English physicist, carried on important researches in the constitution of matter and established the existence of what he called a corpuscle. We now call it an electron. He regarded the "Edison Effect" as being initiated by the escape of electrons from the hot cathode. A cathode is the negative electrode, in this case the hot filament which is the negative electrode in the filament-plate circuit. An anode is the positive electrode, the plate in a tube.

RICHARDSON'S LAW

About 1903 Prof. O. W. Richardson, then at Princeton University, developed a law, a mathematical formula which purported to give the rate at which electrons are emitted from a hot cathode at various temperatures. The number of electrons emitted depends to a very marked extent on the nature of the material constituting the cathode, on the condition of its surface as well as the temperature. Dr. Langmuir later showed that what Prof. Richardson measured in developing his law was the saturation currents.

Dr. Langmuir had devoted a great deal of thought to the nature of the current that flowed in vacuum tubes. He believed that the "Edison Effect" might have a considerable influence on the life of tungsten filament lamps. In view of the work of Prof. Richardson it had been shown that the Edison Effect was due to electron emission from the end of the lamp filament. Dr. Langmuir could not understand why such Edison Effect currents did not interfere with the operation of the lamp. Richardson's law indicated that a high current should flow, which would destroy the filament. The experiments of Prof. Richardson had indicated, and these have been checked by Dr. Langmuir, that a short length of tungsten filament, operated just below the melting point, could emit as high as an ampere of current. This might cause an additional current at one end of the filament of the same order of magnitude as the filament current itself. Dr. Langmuir finally found that it was the space charge effect which prevented a substantial current from flowing.

"CLEAN UP" OF GASES

In the spring of 1912 Dr. Langmuir started experiments to solve the riddle. He carried on researches on the "clean up" of gases. The vacuum in a lamp improves during its burning life, the residual gases in the vacuum largely disappear, "clean up". He particularly studied the clean up which occurred when "Edison current", as it was then called, passed between a hot cathode and a cold anode. He discovered that this clean up was affected by the voltage under which the current flowed.

In July 1912 he started a new series of experiments. He knew that it was useless to attempt to study the clean up of gases in a tube in which gases were continually being driven off from the glass parts and electrodes and because of his knowledge of vacuum conditions, his tubes were prepared from the beginning of these experiments as no other tubes had ever been prepared before. The making of the first tube was carried out under his close direction and supervision by his Assistant, Mr. S. P. Sweetser. Never before had a tube been prepared so thoroughly free in all its parts from the possibility of the evolution of gas.

The tube had two separate tungsten filaments, one for the cathode and the other the anode. Thus current could be passed through both filaments during exhaust to drive out the gases.

Various elaborate studies on the clean up of gases were made on this tube. Different quantities of gases were admitted and different voltages applied on the anode up to 250 volts, while the cathode filament was heated (by passing current through it) so that it would emit electrons. An electric discharge was thus made to pass through the gases for the purpose of studying the changes which occurred.

PURE ELECTRON CURRENT

About a month after these studies of gas clean up had been under way, it was noticed that as the clean up steadily improved the vacuum, the Edison current fell until it reached a minimum, remaining practically constant even when the vacuum condition was still further improved.

A new type of discharge had been found. The voltages used were far beyond that in which blue glow ordinarily appeared, yet no glow did appear and current did flow; as much as 5 milliampores at 250 volts which is 1-$\frac{1}{4}$ watts of electrical energy. The current was a definite value for a given voltage, irrespective of further improvement in the degree of high vacuum; a substantially pure electron current free from ionization.

With the natural skepticism of a scientist, Dr. Langmuir was not satisfied that a pure electron current had been obtained and was still not certain that others were wrong in their belief that no current would flow in an absolute vacuum. So he decided to make a thorough investigation in order to get an understanding of the fundamental laws involved, and thus settle once and for all whether or not pure electron currents could be obtained in a practically perfect vacuum.

In November 1912, three tubes were made from some tungsten filament lamp mounts of peculiar structure in that they each had three loop filaments connected to four leading-in wires. These were selected for the purpose of using the vaporization of tungsten to obtain further cleaning up of the vacuum and so getting a still higher vacuum. By passing a heavy current through the middle loop, it would burn out, vaporizing tungsten with which the vacuum was further improved and leave the other two loops, one for the cathode and the other for the anode.

In testing these tubes 250 volts were applied to the anode, the cathode being heated, by passing current through it, increasingly from 1730° to 3320° Kelvin, the latter being within about 300° K of the melting temperature of tungsten. The tests showed that the Edison current increased with the temperature reaching a maximum value at about 2700° K, after which it remained constant. It was also roughly proportional to the voltage on the anode when the voltage was changed.

SPACE CHARGE DISCOVERY

These tubes followed Richardson's law up to a certain point. Further increase in temperature beyond this point produced no further increase in current, thus deviating from the law at this point. A study of this was made, and by February 1913 Dr. Langmuir's reasoning had evolved the "space charge" effect.

If we are able to arrange matters so that every electron emitted from the cathode passes across to the anode, Richardson's law will become the law of the passage of current through the tube. But while this law held over a certain range in filament temperatures, yet Dr. Langmuir found that as he raised the filament temperatures something always happened which took the control away from Richardson's law and caused the current to become constant at a value depending on the voltage across the tube. His emission curves, his curves of Richardson's law became flat topped; they stopped rising, the law said they should continue to rise, but they became constant. This remarkable and unexpected phenomenon, which enormously impressed Dr. Langmuir when he discovered it, is not explained by Richardson's law, and required an entirely new explanation. It is clear that something is going on in the tube which prevents more than a certain amount of current passing through it; the current is now limited, not by the electron emission from the cathode, but by another phenomenon. This other phenomenon, Dr. Langmuir reasoned, is what we now term "space charge".

As previously stated, Dr. Langmuir also found that a given filament temperature the current is roughly proportional to the voltage, but only up to a certain voltage. He later found that this "rough" proportion to the voltage is accurately proportional to the 3/2 power of the voltage (the square root of the cube of the voltage). Thus when the filament temperature is high enough to emit sufficient electrons, the flow of current to the anode is controlled by the space charge. This current can be varied, depending upon the 3/2 power of the voltage applied on the anode, provided this voltage is not so high as to pull all the electrons across the tube which are emitted by the filament. Under these space charge control conditions, the tube is being operated below saturation, the condition under which a tube is used in a radio receiving set.

When the tube is used with a voltage on the anode always high enough pull over all the electrons emitted, the anode current can be varied by varying the filament (cathode) temperature (the filament temperature being varied by changing the voltage on the filament). The tube is then operated under the condition of saturation, the space charge no longer controlling as it has been neutralized by the high plate voltage. This is the condition under which Richardson's law applies.

DR. COOLIDGE'S X-RAY TUBE

Prior to this time the old "X"-ray tubes had essentially two electrodes to which a very high potential direct current was applied. The cathode was not heated; it operated "cold". To produce X-rays of any particular penetrating power, or "hardness" as it was called, it was necessary to have a particular vacuum; a certain amount of gas was essential. Current was conducted by the gas and from the anode there issued a stream of X-rays.

There are certain ionizing actions going on all the time in nature so that a certain number of ionized gas molecules are in the old X-ray tube. When electric potential is first applied to the terminals of the tube, such of these ionized molecules in the tube will be attracted to the cathode. Striking it, they will knock out electrons. These electrons will be attracted to the anode and during their passage across the tube many will collide with the neutral gas molecules present, ionizing them. These ionized molecules will be attracted to the cathode and the cycle repeated.

It was known that there was a particular gas pressure at which the electrical conductivity of the tube was highest, above and below this pressure the electrical resistance of the tube increased. The penetrating power of the X-rays depended upon the voltage across the tube and the quantity of X-rays depended upon the amount of current flowing through the tube.

As previously stated it was necessary to have a particular degree of vacuum. Unfortunately, as the tube was used, its vacuum was constantly increasing, due to clean up. Various expedients were used to reduce the vacuum when it became too high, but with all of them the life of the tube was limited to about 25 hours.

In December 1912 Dr. Langmuir explained his hot cathode researches to Dr. W. D. Coolidge, who had invented drawn tungsten wire and was Assistant Director of the Research Laboratory, suggesting that Dr. Coolidge produce a new X-ray tube operating on the principle of pure electron flow. Dr. Coolidge finally succeeded in doing this and the new X-ray tube went on the market in the latter part of the next year (1913). Coolidge's X-ray tube was the first pure electron current device (operating above ionizing voltages) commercially made. It operates under the condition of saturation current at extremely high voltages, 30,000 to 100,000 volts. It has entirely replaced the old tube on account of its reliability, ruggedness, ease of manipulation and its unvarying characteristics. It is probable that no one of the many important inventions which have come out of the Research Laboratory of the General Electric Company has contributed so much to the health and comfort of mankind as Dr. Coolidge's X-ray tube which is based on Dr. Langmuir's fundamental invention.

THREE ELECTRODE TUBE

Another important application of Dr. Langmuir's invention followed at once. Late in January 1913 Dr. E. F. W. Alexanderson, also a well known member of the staff of the Laboratory who had made important inventions in wireless, found that he was on the track of two important inventions. These were "geometric" radio frequency tuning, so commonly used in modern radio receiving sets and a method of modulating the output of his high frequency alternator. A three electrode tube with the new pure electron current was what Dr. Alexanderson needed. For the modulation requirement a tube was needed that would modulate real energy and quantities of it.

Dr. Langmuir had a tube built which was very much like the DeForest audion, the anode being a plate. He could not however exhaust the tube to his satisfaction as he had not yet learned how to get the gas out of a plate anode in a small tube. Previous anodes had been tungsten filaments which could be heated to very high temperatures by passing current through them and so getting the gas out.

Mr. W. C. White was then called in to assist Dr. Langmuir in February 1913 and a three electrode tube was made having a filamentary anode, thus avoiding solid masses of metal which Dr. Langmuir did not then know how to clean up. About the middle of March this tube was completed and it was found that with as high as 235 volts on the anode the current was a little over 15 milliamperes, the tube operating below saturation, that is, under the conditions at which the space charge still controls its operation. A few days later the tube was tested as a detector for alternating current signals.

Dr. Langmuir was beginning to think of using 10,000 and higher voltages on the anode of tubes so that with such voltages, and the currents he should be able to get, very large amounts of power could conceivably be controlled by a three element tube.

About the middle of May of that year (1913) Dr. Alexanderson's geometric tuning was successfully accomplished with this first three element tube, together with another similar three element tube that had been made. An anode voltage of 125 volts was used. An interesting feature of this first tube, even after it had been abused by some extremely high voltage tests, was its reproduceability. Tests made in March and afterward in May, with an anode voltage as high as 220, showed that there had been no appreciable change in the characteristics of the tube during this time, a period of two months.

THE HIGH VOLTAGE TUBES

In the latter part of April 1913 Dr. Saul Dushman was also called in to help Dr. Langmuir in his work, taking charge of the high voltage development. About the middle of May, Dr. Langmuir demonstrated to Dr. Alexanderson a high voltage three element tube which would act as a modulator, and indicated that tubes might be built which would operate up to 10,000 volts. In July a tube was produced which operated at 10,000 giving 40 milliamperes anode current. In the fall a tube was built which, in Dr. Alexanderson's laboratory, modulated two kilowatts at 10,000 volts. Such tubes, which were called "Pliotrons", are the basis of modern radio telephone transmission.

During this work on high voltage tubes it had been learned how to get gas out of a plate anode. The anode was either first heated in a vacuum to a high temperature before it was mounted in the tube, or was subjected to a powerful electron "bombardment" when mounted in the tube having a very high vacuum, or both. This electron bombardment is the striking of the plate by the electrons as they flow to the plate under the influence of the voltage on the plate, their impact heating the plate just as repeated blows of a hammer on a piece of metal will heat it. If the voltage on the plate (the anode) be high enough, several thousand volts, and the filament (the cathode) be heated high enough so that it emits an abundance of electrons, the plate becomes heated to a bright red or even white heat. The combined effect of the bombardment (the impact) of the electrons and of the high temperature, is to free the plate from gas. In operating a tube in service, the flow of electrons to the plate in an ordinary radio receiving tube is insufficient to materially raise its temperature, but in the large power tubes used in broadcasting, the heat is sufficient to make the plates red hot. In a very large tube the plate is water cooled.

The immediate commercial exploitation of the new three electrode tube was impossible on account of the Fleming and DeForest patents which were still in force, and for a time it was thought that the Fleming patent interfered with the sale of the two electrode tube, even the Coolidge X-ray tube. But the Fleming patent, it was discovered, was limited to high frequency so the X-ray tube was put on the market.

The successful high voltage three electrode tube led to the development of the two element tube, which was called the "Kenotron", that would rectify as much as 100 milliamperes at 100,000 volts. These were sold for various purposes outside the Fleming patent.

THE THREE ELECTRODE TUBE AS A GENERATOR OF HIGH FREQUENCY CURRENTS

Dr. Dushman, in his high voltage development, conducted experiments with the three electrode tube for the purpose of generating high frequency currents.

Consider a condenser which has a coil of wire connected across its terminals. If a voltage be impressed on this condenser, the instant the voltage is removed, current will flow back and forth (oscillate) through the coil and condenser, continuing until the energy has been absorbed by the resistance of the circuit. The frequency of these damped oscillations will depend inversely on the inductance of the coil and the capacity of the condenser. The frequency can be varied within wide limits.

Suppose this coil and condenser be connected between the grid and filament of a three element tube and that another coil, magnetically coupled to the grid circuit coil, be connected in the plate circuit.

The moment the plate circuit is closed, current will flow through the plate coil which will induce a voltage across the terminals of the grid coil. This voltage will be impressed on the grid of the tube which, if the circuit be so arranged to make the grid positive, will increase the plate current. The increase in plate current will make a further increase in voltage on the grid, continuing until the plate current has reached a maximum.

There now being no further change in plate current, the induced voltage across the grid coil disappears. The condenser, however, has become charged by the voltage induced in the grid coil and now discharges through the grid coil. The discharge of the condenser is accompanied by a decreasingly positive grid voltage which reduces the plate current, the effect being accumulative as it was during the positive part of the cycle.

This change in plate current, passing through the plate coil reacts on the grid coil through the magnetic field common to both coils, tending to keep the oscillations going. Energy is thus transferred from the plate circuit to the grid circuit and the amount so transferred must be not less than the amount lost in the grid circuit otherwise the oscillations will die out. The amount of transfer of energy can be regulated by the closeness of the magnetic coupling of the plate and grid coils.

This ability of the tube to generate high frequency oscillations is now used in all broadcasting stations for the source of power put into the antenna. Its importance was immediately recognized, so numerous experiments were carried out in the attempt to produce a high power oscillator. About 1915 a tube rated at 50 watts and operating at 4000 to 5000 volts was produced with which wireless telephone conversation was carried on between Schenectady and Pittsfield.

EXPERIMENTAL TUBES

During the period 1913 to 1915, work was done by the Research Laboratory on the design of tubes and methods of exhaust which was carried on by Messrs. W. H. Payne and W. C. White. Until the outbreak of the War, all work on tubes was almost entirely of a research and experimental nature.

During the summer of 1915 radio-telephone transmitters had been designed operated from 110 volts direct current, and in December two sets were installed, one on the battleship Wyoming, the other on the Virginia. Early in 1916 these two ships went on their usual southern cruise and the radio telephone sets were satisfactorily used for experimental purposes. They had incorporated in them the method of modulation used today. The equipments were not sold to the Navy, due to the DeForest patent, but simply loaned to them and later returned.

During the latter part of 1913, arrangements were made by the Research Laboratory to utilize the amateur radio facilities of Mr. E. M. Kinney, then of the Railway Department of the General Electric Company, at his home in Schenectady. Tubes were set up at Mr. Kinney's station and code signals received from Honolulu and San Francisco. It is of interest to note that this first set utilized radio frequency amplification and a B eliminator, that is the direct current supply for the plate was obtained from the alternating current electric service in his home, rectified into pulsating direct current by rectifier tubes, the pulsations being smoothed out by condensers. A plate voltage of around 150 was used on the tubes.

During the early part of 1913, arrangements were made with Union College, Schenectady, to utilize their facilities. A number of experiments were made leading to the recording of signals on a tape printing machine. This work was continued during 1914 and it so happened that at the outbreak of the War in August, this apparatus recorded the message from the German station at Sayville, Long Island, ordering all German ships and vessels to proceed at once to the nearest neutral port.

TUBES MADE FOR THE GOVERNMENT DURING THE WAR

Prior to the War, owing to the patent situation, there was no commercial outlet possible for receiving tubes, so that those which were made experimentally had no standardized form of base, filament dimensions, voltages, etc., and no attempt was made to design a tube which could be manufactured in quantity at a reasonable cost.

The coming on of the War changed this because it was early recognized by the Signal Corps of the Army that vacuum tubes would probably play an important part. The French and English had found them of great value for radio communication at the front. As a result the French under the direction of General Ferrie, had designed a small receiving tube that could be manufactured in small quantities. This type of tube, which was known as type R was patented in England in 1916. In one way it was the forerunner of the present tubes, as all the leads came through one stem on which the electrode structure was mounted, as in the present tube.

Anticipating the probable demand by our Army and Navy, the Research Laboratory, in the summer of 1917, turned to the design of tubes which could be made in quantities. Mr. W. C. White designed a small tube which was given to Dr. G. R. Fonda to develop for quantity production with the expectation that there would be a requirement for 500 tubes a day. It was believed that the incandescent lamp factories would be the logical place for their manufacture.

On August 11, 1917, Mr. L. A. Hawkins wrote to the Edison and National Lamp Works asking for their cooperation, the Government having asked the Company to develop a tube interchangeable with the French tube, with a production, by the spring of the next year (1918), of 1000 a day.

For the Edison Lamp Works Mr. H. W. Jackson and for the National Lamp Works, Mr. P. J. Pritchard, together with Mr. W. T. L. Cogger as special engineer to assist Mr. Pritchard, were appointed to supervise the commercial development and manufacture of tubes.

On September 11, 1917 Dr. Fonda sent specifications of the tube he had developed to the Edison and National Works. After much experimental work had been done by both the Edison and National Works, samples were made and on September 24th a meeting was held at Harrison, N.J., Lieutenant Bown of the Signal Corps, engineers of the Research Laboratory and of the Edison and National Works, being present. Two tubes were decided upon, one for receiving purposes and the other for transmitting purposes.

Both Works intensively continued their development now that the general construction had been decided upon. In all cases, except where machine operations were possible without affecting the quality of the product, an endeavor was made to follow the processes and operations exactly as performed in the Research Laboratory in Schenectady.

The tubes incorporated a spiral filament of the double helix form, commonly employed in automobile headlight lamps of that date. The grid was a similar double helix, but larger. The plate was a little cap of nickel. Although this did not use the filament area to the greatest advantage, this design fitted in more easily with lamp factory methods. The grid and filament mounting were similar to the mounting of filaments in a lamp. The cap shaped nickel plate was punched out, and could also be mounted with modifications of lamp factory welding machines in existence.

MANUFACTURING PROBLEMS OF QUANTITY PRODUCTION

However, the factories soon found that they had a real problem on their hands. Stem making in lamps was considered fairly easy, and it was with confidence that they converted over a stem making machine to put six wires in a stem, spaced one-sixteenth of an inch apart. Soon all the difficulties occurred that could possibly happen to stems - cracks, leaks, short circuits, burnt welds and all sorts of glass troubles. Each difficulty required every bit of lamp knowledge and experience that could be commanded in order to solve the troubles.

Coiling the filament and grid required the most painstaking and careful operations. Mandrels of molybdenum were made and accurately threaded to give proper coil size, shape and pitch. The mandrels were carefully wound with filament and grid wire and sintered in hydrogen furnaces. Mounting the filament and grid was found to be most difficult, due to the accuracy required and the smallness in the spacing between the filament and grid as well as the necessity of mounting without any strain.

All the tubes made at Schenectady had been exhausted by means of mercury condensation pumps. At the Edison Works, Mr. Jackson had been unable to make the mercury pumps work properly and, during the time when a special engineer from the Research Laboratory was putting them in shape, he decided to try out the oil pumps used in lamp exhaust even though doubt had been expressed that such pumps could properly exhaust radio tubes. By intensive work he was able, with a special combination of chemicals, called "getters", used in lamp manufacture, to exhaust tubes much more rapidly and as satisfactorily as Schenectady had done with mercury pumps. This information was transmitted to the Research Laboratory. The National Lamp Works, after further details had been sent them, were also able to satisfactorily exhaust tubes by means of oil pumps.

During all this time Dr. Fonda had also been making tubes, and sample experimental tubes from both Works were sent him to test. Of the experimental tubes from in the lamp factories, made on a basis of what was expected to be practical quantity production, many were found to be quite superior to the tubes made in the Schenectady Laboratory, although many were also found to be considerably inferior. This possibility of good quality commercially made tubes gave every encouragement to the lamp factories to be able to produce them in large quantities.

Equipment for production and testing in quantities therefore was set up and experience gained in further improving the quality and manufacturing facility.

NAVY ORDER FOR 1000 TUBES

Early in December the Navy had come forward with a demand for tubes, an order being placed for 1000 receiving tubes on the basis of six samples produced by the National Works sent by the Research Laboratory to the Navy. This was the first actual order for tubes from the Government, and the necessary steps were immediately taken to build up an organization in the lamp factories, laying out equipment for considerable quantity production. It is interesting to note that of these 1000 tubes, made by the National Works having had less than a month's real experience with this new problem, only seventeen failed to pass the severe mechanical, radio and electrical tests, a rejection of less than 2% for all causes.

These tubes were designated by the Navy Department as Type CG-886. The filament was designed to operate from a two-cell lead battery, about 4 volts, or through a resistance from a three cell (6 volt) battery. The plate voltage used was about 40. They were used as detector, oscillator and audio amplifier tubes, both aboard ship and on land stations. The base used was the type originated by Dr. DeForest which was standardized by the Navy. It was similar to the present small base except there were only three prongs, the fourth contact being made through the bayonet pin on the side. A moulded compound was utilized which was abandoned shortly after, not to be revived for nearly eight years.

ACTIVE INTEREST BY THE SIGNAL CORPS

The Signal Corps was now becoming actively interested in the sample tubes made by the General Electric Company, as compared with the Western Electric tubes they were using. Several designs had been submitted owing to considerable changes necessary to meet their special requirements. The Chief Signal Officer then asked the General Electric Company to endeavor to make the Western Electric type of tube, as this tube was giving satisfactory results and a greater production was desired. To this end representatives of the Research Laboratory, the Edison and the National Works investigated the process and method of manufacture of the Western Electric type of tube which was thoroughly explained to them by representatives of the Western Electric Company.

It was estimated that not more than five percent of the labor required for the tube could be supplied by the lamp factories, as the greatest part of the work was foreign to commercial lamp manufacture, so that most of the labor would heva to be specially trained. Furthermore, the equipment necessary did not fit into the layout of lamp factories. This would greatly delay the start of production, while production of the G. E. type of tube could be begun at once. It was estimated that two months would be necessary before any Western Electric type of tubes, probably 25 per day, could be under production, whereas production of the G. E. type would have risen from 100 per day at the start to 600 per day during this two month period. The equipment necessary for the Western Electric type of tube was 90% special as compared with 80% regular lamp equipment for the G. E. type.

Both the Western Electric Company and the Chief Signal Officers were convinced, after the matter was thoroughly discussed, that the manufacture of the Western Electric type of tube was not a practical proposition in incandescent lamp factories.

SIGNAL CORPS ORDER FOR TUBES

On January 21, 1918 the Research Laboratory received a telephone order for 80,000 G. E. tubes, deliveries beginning within a week at the rate of 500 a week, increasing to 1500 a week within a month thereafter, to 3,000 a week within two months and to 6,000 a week within three months which rate was to be maintained until completion of the order. The order was divided equally between the National and Edison factories.

The production schedule demanded was much less than what the factories had stated they could do, it appearing that the Government officials did not believe that a production as great as had been estimated could be obtained. The officials stated, however, that if the tubes came through satisfactorily, the rate of production could be doubled.

These tubes were called by the Signal Corps as Type VT-11, to be used for detector, oscillator and amplifier operation in receiving sets in which the Western Electric type of tube (called VT-1) was used. The tungsten wire filament was double spiral helix rated at 1.1 amperes, at about 4 volts, to be used on a two cell lead storage battery. The grid was a larger double spiral helix of tungsten wire, and the plate a nickel cap on which voltages up to 60 could be used, The bulb was the S-14, as used in the 10 watt sign lamps and the base had four prongs mounted on a porcelain disk which was fastened to a brass shell. The porcelain disks were made in the Schenectady factory and shipped to the Providence Base Works where the shells and pins were put on.

An arbitrary method of comparing quality was used. By means of a "Cable Box", the amplification rating was measured by the equivalent number of miles a signal could be sent through a cable to be received at a certain strength. The first tubes had a rating of 8 miles. Within a month this rating was raised to an average of 12 miles and before the National Lamp Works had made 10,000 tubes the average was 16 miles. Before half the Signal Corps' original order had been filled the average rating was over 20 miles. The direct measure of quality varies as the square of these ratings or in the ratio of 64 for the first tubes to 400 for the last tubes, an increase in quality of over six times. The life of the tubes was also increased from nearly 300 hours (200 hours minimum requirement) to 2,000 hours and as a result, the tubes gave the Government over seven times the life expected. In addition to this, wonderful improvements were made in the uniformity of the product.

All this progress, however, was not made without difficulty. On one occasion, out of nearly 2,000 tubes that the National Works had made up, not a single one was good for anything. Several times the factories were confronted with losses of thousands of dollars, due to imperfect raw materials and uncontrollable circumstances. All of these problems kept every man working night and day, and required the best possible supervision and engineering.

One of the handicaps was the limited production schedule at first imposed by the Government. Continued requests were made for release from this restriction in order to make it possible to obtain more efficient operation by means of greatly increased rate of production. Finally the superior quality and operating characteristics of the tubes excited the interest of the allied governments. The Research Laboratory received a request from the British Admiralty for tubes. The National Works at once began to make plans to reach a production of 36,000 tubes per week within two months. The order from the British, however, failed to materialize but the Signal Corps gave permission to the National Works to increase production which was increased to 10,800 maximum per week. The Signal Corps order was therefore completed ahead of schedule and the factories were forced to ask for more orders to keep the special organization and plants in operation. It became evident however, that it was necessary to cut down production as more tubes were being made than the Government could handle.

In June 1918 the Signal Corps ordered 20,000 more VT-11 receiving tubes and the Navy Department 10,000 (called by them CG-890).

Another receiving tube, which was in the development stage at the time the armistice was signed (November 11, 1918) was the type VT-13. This was a modification of the VT-11, the endeavor being to improve both the ruggedness of the tube for airplane service and its radio characteristics. The service of this tube was identical with the VT-11.

SIGNAL CORPS TRANSMITTING TUBES TYPES VT-12 AND VT-14

At the same time the order for the 80,000 VT-11 receiving tubes was placed (January 21, 1918), the Signal Corps ordered some transmitting tubes, type VT-12. In appearance this tube was very similar to the receiving tube except that the filament was designed for 1-1/3 amperes at 7 volts and the plate made of molybdenum on which voltages up to 400 could be used.

Production was requested at the start at the rate of 50 per day and on account of the high plate voltage it was necessary to use a mercury diffusion pump for their exhaust. Production started at the Laboratory at about ten per day until arrangements could be made for the factories to use mercury pumps when production in about two to three weeks could be obtained at a rate of from 50 to 100 per day.

The design of this tube was later changed to increase its transmitting range, the filament current being increased to 1-3/4 amperes. The original VT-12 was developed for use in telephone transmitting sets in which the Western Electric type VT-2 was used and had a range of about three miles. The improved tube was called the VT-14 and had a range of from 10 to 15 miles. It was also adopted by the U. S. Navy (called by them the CG-1162) and was used on submarine chasers and flying boats. Several thousand transmitting tubes were made.

Another type of transmitting tube, VT-16, was in the development stage for the Signal Corps at the end of the war, and was constructed with the endeavor to improve the mechanical strength of the tube for airplane service and to perfect its electrical and radio characteristics.

OTHER TUBES MADE

An amplifier tube, known as type CA, was developed for use by the Navy in connection with high speed photographic receiving apparatus. It was a special tube designed to obtain maximum amplification. It embodied a tungsten filament with a finely wound tungsten grid and a tungsten plate.

A regulator tube, type TB-1, was made for use in regulating the voltage across the terminals of a fan propelled generator for airplanes. This was a two element tube having a tungsten filament and a molybdenum plate, and was so connected into the field and armature windings of the generator that, with airplane speeds varying from 40 to 180 miles per hour, corresponding to armature speeds of 3,500 to

18,000 revolutions per minute, the voltage did not vary more than ten percent. Several thousand of these tubes were made.

POST WAR WORK

During the period between the end of the war in November 1918 to the formation of the Radio Corporation of America, about a year later, there was relatively little done by the General Electric Company in the further development of receiving tubes. The several types of tubes developed during the war period were technically available but could only be sold to the Government because of the patent situation.

Quite a little work however was put into the development, by the Research Laboratory at Schenectady, of transmitting tubes and radio transmitters utilizing large vacuum tubes. A considerable amount of this development was along lines of interest to the U. S. Navy which included radio telephony.

MARCONI AND WESTINGHOUSE TUBES

Just prior to the formation of the R. C. A., the Marconi Company advertised and sold tubes. They were somewhat similar in general construction to the French type R tubes, having a tungsten filament designed for 3.65 volts, 0.65 amperes. Two types were made one having a "hard" (high degree) vacuum for amplification, the other being a "soft" tube, having a relatively poor vacuum, and used as a detector. The period during which these tubes were sold was a short one, as the R. C. A. Company soon took over the interests of the Marconi Company.

The Westinghouse Company developed a tube having a 4 volt 0.8 ampere filament which they called an "aeriotron". It was made with "hard" vacuum (WR-21A) for amplifying and "soft" (WR-21D) for detector purposes. The Westinghouse Company did not join the R.C.A. until more than a year after its formation, during which period they developed another aeriotron (WD-11). It was a "hard" tube having a 1/4 ampere, 1.1 volt oxide coated platinum filament, current for which was to be supplied from a single standard dry cell.

FORMATION OF THE RADIO CORPORATION OF AMERICA

The Marconi Wireless Telegraph Company of America, which was mainly engaged in ship to shore Radio telegraph operation, owned the Fleming two element tube patent. The DeForest Radio & Telegraph Company owned the DeForest three element tube patent and, for a short time, manufactured three element tubes, but a suit brought by the Marconi Company resulted in a decision that the DeForest three element tube or "Audion" infringed the Fleming tube patent. The American Telegraph and Telephone Company could not manufacture, through its subsidiary the Western Electric Company, electron discharge tubes unless it acquired rights under the Fleming patent (it had obtained rights under the DeForest patent). Dr. Langmuir's patent application on the pure electron discharge tube was pending, and was owned by the General Electric Company. Neither could the General Electric Company manufacture radio tubes on account of the Fleming and DeForest patents. There are also other construction and detail patents owned by these and other concerns which were considered necessary in the construction of radio tubes. This conflict of patents, owned and controlled by opposing interests, restricted the development of radio.

The Radio Corporation of America was organized on October 17, 1919. About a month later the R. C. A. entered into an agreement with the Marconi Company whereby it obtained, in exchange for stock, the patents, etc. of the Marconi Company. Agreements of this character were also entered into at various times with the G. E. Co., the A. T. & T. Co., the Western Electric Co., the United Fruit Co., which operated a fleet of vessels equipped with wireless as well as some land stations, the Wireless Specialty Apparatus Co., a subsidiary of the United Fruit Co., the International Radio Telegraph Co., the Westinghouse Electric and Mfg. Co., and the Radio Engineering Company of New York. Thus the R. C. A. was enabled to develop the radio industry. It should be remembered, however, that at the time of the formation of the R. C. A., radio broadcasting did not exist and, therefore, outside the field of commercial communication which was largely of a trans-oceanic nature, the only business of the R. C. A. was selling radio apparatus, parts and tubes to a group of amateurs and radio experimenters, of which there was probably about five thousand in number.

THE FIRST R. C. A. TUBES

At a conference held between representatives of the General Electric Company and the Radio Corporation, the need was indicated for a new type of tube for detection and audio amplification. As a result, there was developed in the Research Laboratories and in the lamp factories, Radiotrons UV-200 and UV-201. These tubes, at the start, were identical in mechanical construction, the only difference being that the UV-200 contained about 50 microns pressure of argon gas. A micron is the pressure equal to one thousandth of a millimeter height of mercury; 760 millimeters, or about 30 inches, height of mercury being the approximate pressure of the atmosphere at sea level. A micron is therefore about 1/760,000 atmospheric pressure.

A filament voltage of five was used. The wide spread use of storage batteries in automobiles had standardized and made the three-cell lead battery the best for filament operation. A lead battery has a normal voltage, fully charged of about 6 volts, dropping to about 5½ volts at discharge. It was thought best to allow ½ volt for the drop in the battery connecting wires, the wires in the radio set and the contacts.

The plate was made of nickel, the grid side rods of nickel wire, the grid wire of molybdenum and that part of the leading-in wires, inside the tube, of nickel. The filament anchor and the filament itself was tungsten. Later, for a short time after the automatic grid winding machine was adopted, the grid wire was changed to nickel but, as this proved too soft in this instance, the grid wire was then changed to nichrome, a wire used in electric heating devices.

These tubes had the same base as was utilized in the Signal Corps tube VT-11 and the same general structure as used in experiments for the Signal Corps VT-13. With the exception of slight variations in filament voltage, they were practically identical to the VT-13 design of 1918 and 1919.

R. C. A. TUBE NOMENCLATURE

Mr. G. H. Clark of the R. C. A., who had had wide experience in the Signal Corps, the Navy and the Marconi Company, was requested to make up apparatus designations and catalogue numbers. He made a system of model numbers to designate class and items of apparatus. It was designed to use letter prefixes for units of apparatus and another set of letters for complete pieces of apparatus as a whole, such as complete receivers or transmitters.

The letter U was chosen to signify a unit, distinguished from an assembly of units; R, as resister; C, a condenser; T a terminal or socket; etc. On this basis V was chosen for vacuum tube, probable having in mind the English term "valve" and which was used previously by the Marconi Company. Numbers started originally with 200 for vacuum tubes, therefore UV-200 represents the first type of vacuum tube released and sold by the R. C. A. For a short time afterward, each new type of tube that came into use was given a number in the same series.

THE THORIATED TUNGSTEN FILAMENT

Dr. Langmuir discovered that, at any given temperature under certain conditions, metallic thorium has an enormously greater emission than tantalum, tungsten or any other metals which have been used as cathodes. Dr. DeForest had first used tantalum. It would appear that a thorium filament would be better cathode than a tungsten filament. The nature of the metal thorium, however, is such that it cannot be operated at a temperature high enough to take advantage of its superior emissive qualities. Thorium melts at about 2000° K which is about 1700° below the melting point of tungsten. Long before a thorium filament could be heated hot enough to give out sufficient electrons per unit surface, the filament would vaporize quickly or even melt.

Here is a material, thorium, of wonderful emissivity at any given high temperature, but having the property that the forces which hold its atoms together are so small that when an attempt is made to raise its temperature to get a reasonable emission, the effect of the high temperature overcomes the cohesion of the mass and the individual atoms fly off (vaporize) or the whole mass becomes a liquid (melts). The limitation on the use of thorium for cathode purposes, a limitation that seemed inherent in the nature of the metal itself, was overcome by Dr. Langmuir in a very beautiful series of inventions.

The first invention was the distribution of the thorium atoms on the surface of a tungsten filament in the form of a layer of exceedingly minute thickness; actually it is only one atom deep no more and no less, incredible as it may seem. The result is that, due to inter and intra-atomic actions, the atoms of this atomic layer of thorium are held to the tungsten by a force much greater than that which holds together the atoms of a mass of thorium. The thorium atoms on the surface of the tungsten filament will remain in place hundreds of degrees higher than that at which the corresponding atoms on a thorium filament will fly away. In fact such a layer will remain solidly on a tungsten filament at a temperature 300 degrees above the melting temperature of thorium.

The history of science does not disclose any prior resort or suggestion to this expedient, this artificial elevation, as it were, of the melting and vaporizing points of a substance by distributing it as an atomic layer on the surface of another more refractory substance.

One way of obtaining such an atomic layer of thorium on a tungsten filament could be accomplished by locating near the cathode a wire of thorium which could be vaporized by passing current through it. Some vaporized thorium would deposit on the cathode which would reduce to a layer one atom deep the moment the cathode (the tungsten filament) is heated to the desirable operating temperature. In practice however such a cathode would have a short life; the atomic film is delicate and easily destroyed. It is therefore desirable that the film be automatically renewed; that there should constantly be fresh atoms of thorium coming along to replace any atoms which have been evaporated from the surface, or driven off the surface by ion bombardment or oxidized by the action of gases in the bulb. What is wanted is a reservoir of thorium, an extra supply which can be fed to the surface as it is needed. The method by which Dr. Langmuir provided this reservoir is most interesting.

The drawn tungsten wire used in incandescent lamps at that time (1913) contained a small quantity, perhaps half of one percent of thoria, an oxide of thorium, for the purpose of preventing "offsetting", the sliding sidewise of short sections of the filament, when the lamp was burned on alternating current circuits. Dr. Langmuir discovered that under proper temperature conditions a tendency existed for the tungsten to reduce the thoria to metallic thorium, the released oxygen of the thoria combining with the tungsten to form tungsten oxide. The metallic thorium atoms thus released, diffuse through the tungsten filament and finally come to the surface.

By heating the thoriated filament to about 2900° K for about a minute, a supply of metallic thorium is obtained by the relatively fast reduction of thoria to thorium at this temperature. The surface of the filament is also "purified", released from contaminating substances. Such atoms of thorium which diffuse to the surface during this period immediately vaporize from the surface at this temperature. The filament is then "activated" by heating it to a temperature in the neighborhood of about 2200° K which causes the thorium atoms to diffuse to the surface so that in a short period of operation at this temperature the filament has a layer of thorium atoms on its surface. At this temperature, the supply of thorium in the body of the filament diffuses to the surface at a rate sufficient to replace those atoms leaving the surface, provided great precautions are taken to protect this delicate atomic film in place.

The film may be attacked in various ways; for example if there is any oxygen in the bulb it will immediately oxidize and destroy the film for thorium is a highly oxidizable metal. This would be bad enough if the oxide of thorium were fairly volatile so that it would at least get out of the way and would allow the film to reform. But thoria is a highly refractory material otherwise it could not be used in tungsten filaments. Thus from the point of view of the presence of oxidizing gases in the bulb, the vacuum required must be extraordinarly high. To obtain reasonable life the presence of oxygen must not exceed a pressure of a millionth of a millionth of a micron.

Another point of great importance is that while any serious ion bombardment is destructive of a filament, no great harm will be done if several layers of atoms are knocked off the surface of a pure tungsten filament by a slight bombardment. Such a slight bombardment, however, would be fatal to the atomic film of thorium on the tungsten filament. Thus to prevent even this slight ionization, it is essential that the vacuum be almost inconceivably good, there must be a great absence of any gases, especially oxidizing gases.

Owing to the fact that the very highest vacuum condition was necessary to obtain emission from thoriated tungsten, its immediate utilization in the factory in practical tube manufacture was prevented and a great deal of laboratory work was necessary before it could be used.

During the summer of 1914 some experiments were carried on with potassium vapor in a two element tube for the purpose of noting the change of space charge effect. Mr. W. C. White noticed, entirely by accident, that he was obtaining thoriated filament emission from these tubes, and although not nearly stable, it was remarkably more constant than in early experiments. Dr. Dushman confirmed this result with tests on some photo-electric cells which had a thoriated tungsten filament (used unheated as the anode when operated as a cell) and a coating of potassium on the inner wall of the bulb.

After this encouraging result quite a little work was done in an attempt to utilize potassium, but potassium was difficult to handle. Work was then abandoned for the time being and during 1917 and 1918 this work stopped entirely due to war activities.

During the summer of 1920 Dr. A. W. Hull of the Research Laboratory at Schenectady developed the use of magnesium which not only provided the high vacuum necessary for thoriated filaments but also was much easier to handle than potassium.

The principle of this, as a vacuum "keeper", is the deposit on the inside of a tube of a metal which will easily combine with oxygen and certain other gases. If, for example, a molecule of oxygen is given off by the anode or by some other part of the tube, the chance that the molecule will strike the wall of the tube, covered as it is with the metallic deposit, is infinitely greater than the chance it will strike the filament. And when it strikes the metallic deposit that is the end of it combining with the magnesium to form a solid compound.

When magnesium is vaporized in the bulb, the hot vapor also acts as a vacuum "getter" to improve the vacuum similar to the way phosphorus is used in incandescent lamps. At the temperature at which the bulb operates, magnesium has such a low vapor pressure that there is no tendency for it to cause ionization.

During the years 1919 and 1920 the Research Laboratory carried on work on high frequency furnaces which were operated by vacuum tubes. The principle consists of sending a high frequency (from 50,000 to 1,000,000 cycles per second) alternating current through a coil of wire. The high frequency durrent is generated by an oscillating three element power tube. A metallic object, put inside this coil, will have eddy currents generated in it, similar to the current generated in the secondary of a transformer. These eddy currents are sufficient to heat the metallic object to a high temperature.

A piece of metallic magnesium, put inside a tube can be readily vaporized by means of a high frequency current by placing the coil, through which the high frequency current passes, over the tube. Removing the coil allows the magnesium to condense, which deposits on the wall of the bulb. The high frequency current causes the other metallic parts of the tube, the plate, grid, etc., to heat up driving the occluded gases out of them.

During 1920 and 1921 the Harrison factory by accident used some tungsten filament wire containing thoria for the manufacture of the UV-201 tube. It was found that a very small percent of the production of this thoriated filament tube actually operated by thorium emission in a satisfactory manner when the filament voltage was reduced to half the normal value.. This reduction in voltage caused the filament to operate at about the proper lower temperature. The pure tungsten filament operates at about 2400° K, the thoriated at about 1950° K.

During the latter part of 1920 considerable activity in the Research Laboratories took place on the development of the thoriated filament. The addition of carbon was suggested by Dr. Langmuir. Dr. Dushman demonstrated its practicability.

Although there is no complete information on the effect of carbon, it is believed that its principal advantage is in the increased production of thorium from thoria and increasing the speed of the diffusion of thorium from the interior to the surface of the filament.

Carbon was introduced first in the form of lamp black, mixed with powdered tungsten, prior to the formation of the slug of tungsten from which the filaments are made. The amount of carbon that could be so introduced was limited because of difficulties in drawing the wire and handling. In drawing the wire it became brittle. Aquadag, which is fine graphite mixed with water, is now used, about 1% being put in the slug together with about 1½% of thoria. After the slug is sintered, no free carbon is found but probably a tungsten carbide is formed which makes a good reducing agent for the thoria.

Another method of introducing carbon is to flash the filament of completed tubes before exhaustion in a hydrocarbon vapor such as acytelene. This method of carbonizing after making the wire is only used at present in transmitting tubes or on tubes requiring more than 2,000 volts on the plate.

The electron efficiency of a small thoriated filament, in which carbon is introduced into the slug, varies between 25 and 45 milliamperes per watt. With a thoriated filament carbonized in hydrocarbon vapor, the electron efficiency varies between 50 and 100 milliamperes per watt. In comparison it should be noted that the pure tungsten filament used in the UV-201 tube had an electron efficiency of only 1½ to 2 milliamperes per watt. For higher power tubes, using a heavy pure tungsten filament, efficiencies between 5 and 15 milliamperes per watt can be obtained.

It was now believed that practical thoriated tungsten filament tubes could be made and work was started first at Harrison and then at Cleveland. The object was first to produce highly efficient dry battery tubes and second, improved form of storage battery tubes requiring less filament wattage. For receiving sets there was produced the UV-199 and the UV-201-A tubes. The first thoriated tungsten filament tubes sold, however, were 50 watt power tubes, purchased by the United States Government.

THE UV-199 TUBE

For dry battery receiving tube purposes it was decided that low filament current was advantageous utilizing the smallest size filament wire which the factories believed they could use. This was the 0.6 mil wire which could operate at 0.06 amperes, the filament length being that for a 3 volt rating. This gives a filament wattage of 0.18 as compared with 0.275 for the WD-11 tube whose filament consumed 0.25 amperes at 1.1 volts.

The early work of development was done with a form of double ended tube in which the base was eliminated but, after further consideration, it was decided to use a one ended construction as it permitted simpler manufacture and fitted in better with the receiver design of the engineers. The double ended construction had certain advantages, eliminating the cost of the base and the basing operation and reduced the inter-electrode capacity. The most important inter-electrode capacity is that between grid and plate in the case of a radio frequency amplifier. This is due to the fact that the electrical capacity between grid and plate tends to produce oscillations which prevent amplification.

The actual work on the UV-199 tube started in the Research Laboratories about February 1, 1921, first incorporating a filament wire of 0.9 mil in diameter (about 0.135 amperes). In June and during July of that year, samples were supplied to the Radio Department of the G. E. Co. for consideration in connection with the future design of receiving sets. In October the first samples were received from the Harrison factory. In December the 0.6 mil wire was introduced, producing a 0.06 ampere filament. In May of the next year (1922) the design was changed to one ended construction and manufacture went on actively in the factories with a small experimental production. The tube had a total emission of about 6 milliamperes, about as much as that of the old UV-201 tube.

The UV-199 tube was announced by the R. C. A. during the New York Radio Show in December 1922. The tubes however were not put on sale and made available to the public until about the middle of April 1923. During January 1923 the Harrison factory was producing about 200 satisfactory tubes per day and there was a great demand for increased production in order to meet the demand for the receiving set, Radiola #4, under production, which used three of these tubes. By April the production in the Harrison and Cleveland factories had each reached to about 1500 per day. By about May the top filament support was changed to soft nickel to assist in overcoming microphonic troubles, the noise caused by vibration of the filament.

A difficulty had arisen with the tube, due to the fact that with the three dry cells used, a voltage of 4½ was obtainable when the cells were new. Thus if the filament rheostat was improperly adjusted with new cells, the thoriated filament was soon deactivated. It was found that a single dry cell was very satisfactory when operated to not below 1.1 volts, so the length of the filament was increased to correspond to 3.3 volts, consuming 0.06 ampere at this voltage (about 0.057 at 3 volts). This increased the total emission from about 6 to 7 milliamperes (at 3.3 volts). This went into effect during May of the next year (1924).

The tipless construction was started in production about March 1924. In making this change the maximum overall length was kept the same so that the actual length of the bulb was slightly increased. By the end of June the production was about completely changed over. All the Radiola #8 receiving sets utilized this tip-loss tube.

By the fall of 1924 the black moulded bakelite base had superseded the brass shell base in factory production. This change was made entirely on the basis of improved quality and resulted in an increased cost of manufacture at the time the change was made. The moulded bakelite base gave an improved appearance and permitted greater uniformity of essential dimensions of the base. For a time it increased the difficulties in basing and marking.

THE STANDARD OR UX BASE

At this time, the latter part of 1924, there were in use three different receiving tube bases. The Navy standard base was a so-called bayonet type and was used on the larger bulb receiving tubes such as the UV-200 (and UV-201A). The UV-199 base was also of the bayonet type but was smaller than the Navy base and had shorter contact pins requiring a type of socket which makes contact on the bottom of the pins. This base was used only on the UV-199 tube. The WD-11 base was of the "push" type and had long pins which make contact on the sides. One of the pins was of larger diameter than the others and was connected to the plate of the tube.

The push type socket has advantages over the bayonet types in that the contacts are more certain and the socket construction is simple. However, in view of the large number of Navy type sockets already then in use, estimated at two thirds of the total, it was necessary in adopting any program of standardization to make provision for these sockets, otherwise it would have been necessary to continue the Navy base.

Standardized bases were adopted which were thereafter used on all receiving tubes, superseding the three other bases and at the same time permitted the use of the larger standard base in the navy socket. The new standard bases were made in two sizes but with identical contact pins. The larger size has the same diameter as the Navy base and the same bayonet pin on the side. The contact pins, however, are longer than in the Navy base and the two pins connected to the filament are larger in diameter than the grid and plate pins. The distance from the bayonet pin to the end of the contact pins is the same as the Navy base.

The smaller size standard base has exactly the same pin dimensions and arrangements as the larger size base, but the moulded part is approximately the same size and shape as the moulded part of the WD-11 base.

The result of this standardization, announced August 1,1925, was that the UV-199 and WD-11 bases and their sockets became obsolete, the large size standard base could still be used in the old

Navy socket and both the large and small standard bases could be used in the new standardized "push" type of socket.

THE UX-199 TUBE

Production of the 199 tube with the UX base was started in April 1925, the UX-199 tube being announced August 1, 1925.

In June 1926 the diameter of the filament was changed slightly so that at 3.3 volts it consumed 0.063 amperes (0.060 at 3.0 volts). This increased its total emission from about 7 to 8 milliamperes at 3.3 volts.

Since January 1927 less activity has taken place in the design of receivers to utilize this dry battery tube.

THE UV-201A TUBE

The other receiving tube developed to utilize the thoriated tungsten filament, the UV-201A tube, was designed to replace the UV-201 tube. The same general processes used in the 199 tube were utilized. The structure and filament wire being larger and the spacings bigger, manufacturing development was therefore relatively simpler.

Work was started in the Harrison and Cleveland factories on this tube in April 1922 and during the summer the development work in the factories was actively under way. In October production on the old 201 tube with the pure tungsten filament was stopped and production on the 201-A thoriated tungsten filament started on a small scale. This could be done because sufficient stock of the old 201 tube had been made to last until about the end of the year. The UV-201-A tube was announced by the R.C. A. at the same time as the UV-199, at the New York Radio

Show, December 1922. It consumed but $\frac{1}{4}$ ampere filament current at 5 volts as compared with 1 ampere for the old 201 tube and had an emission of about 45 milliamperes as compared with about $7\frac{1}{2}$ for the other.

The UV-201-A tube at once became very popular and by August 1923 it enjoyed a wider sale than any other tube. At no time during the development of its manufacture were serious difficulties encountered, its life was satisfactory and the production was free from any period of trouble.

In the latter part of 1923 a decision was made to decrease the distance between the two inner surfaces of the plate, known as the "plate diameter", so as to increase the mutual conductance.*

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*There are two circuits in a three element tube, the filament-grid circuit and thefilament-plate circuit. The mutual relation of these two (in the conduction of a signal through the tube), called the mutual conductance, is indicated by the amount of change in plate current produced by the change in voltage on the grid.

Conductance is the opposite of resistance. Resistance is measured in ohms, so the word OHM spelled backward, MHO is a unit of conductance. This, however, is a very large unit for the measurement of the mutual conductance of a tube, so a millionth of this unit, called a MICROMHO (micro being the Greek for millionth), is used.

The mutual conductance depends upon the steepness of the curve at the point of normal grid voltage. The steepness also depends on the plate voltage, so the mutual conductance of a tube varies, depending upon the plate voltage and grid bias used.

The mutual conductance of a tube expresses, better than any other single factor, its value as an amplifier. However, when comparing tubes designed for different classes of service, this factor must not be given too much weight. For example, the UX-120 tube (a dry cell power tube) has but two thirds the mutual conductance of the UX-201A tube (at 135 volts on the plate and the recommended grid bias for each) yet is capable of delivering about twice the undistorted power output given by the UX-201A tube. On the other hand, if it were possible to increase the mutual conductance of the UX-120 tube, its efficiency as an amplifier would be improved.

This change in "plate diameter" of the UV-201A tube introduced a complication because it resulted in a slight change of capacity between the grid and plate. At this time the neutrodyne type of receiving set was enjoying an increase in popularity. The successful operation of these sets depended upon the capacity balance used in connection with these sets which, however, could be readily overcome by a slight readjustment of the small balancing condensers used in the sets. The Cleveland factory continued the production of the older wide "plate diameter" for a considerable time after the new narrower "plate diameter" construction was put into manufacture at the Harrison factory. Hence for a period of a few months, the product obtained by the public showed quite a difference in results in neutrodyne sets that had not been rebalanced.

The tipless UV-201-A tube was introduced about March 1924 and the bakelite base about October of that year, both at the time these improvements appeared in the 199 tube.

Up until the early part of 1924 there had been a difference in the appearance of both the 199 and 201-A tubes as made in the two General Electric factories. Tubes made in Harrison had a silvery appearance due to the magnesium deposited on the inner surface of the bulb; Cleveland tubes had a rainbow appearance due to the use of a considerable amount of phosphorus. This was not only a difference in appearance but the greater use of phosphorus produced the equivalent of nearly 1½ volts negative grid bias. This made a noticeable difference of operation in circuits where no "C" bias battery was employed. Finally it was decided to standardize on a bulb predominately silvered.

The effect of phosphorus in creating negative grid bias was caused by a deposit of the phosphorus on the surface of the grid which varied the contact potential of the surface of the grid with respect to the filament. Phosphorus only sometimes gave a definite and constant bias. These variations in bias not only caused variations in the operation of different tubes but also a variation in the operation during life of many tubes.

It was found during the summer of 1924, that if the grids of tubes were sprayed with aquadag, not only was the natural grid potential kept much more constant than by use of phosphorus but there was also an increase in the life of the tube. It is surmised that the carbon of the aquadag acts as a scavenger. Coating the grid is still in use today although the spraying method is no longer used.

UX-201A TUBE

By August 1925 all 201A tubes manufactured were equipped with the large UX-standard base, the UX-201A tube being announced by the R. C. A. at this time, the same time the UX-199 was announced.

During June 1926 the short shell large standard UX moulded base was introduced in the 201A tube. In the fall of that year steps were taken to improve the mechanical strength of the tube and in

December 1926 the mica top support was adopted which greatly reduced microphonic troubles. However, these mica supports were not put into production on a large scale until May 1927.

During the summer of 1927, nickel plated contact base pins were introduced to supersede the brass pins.

LOUD SPEAKER TUBES

The use of loud speakers created a demand for a tube of greater output to operate the speaker at considerable volume. The output of a tube does not have to be very great for headphone operation. In order to produce distortionless reproduction at considerable volume, it necessitates a tube having a large variation in plate current operated with high voltage on the plate. The large variation in current is limited to that portion of the straight part of the plate current - grid voltage characteristic curve of the tube at negative grid voltages.

In the design of this tube, large cathode and anode areas are essential because mutual conductance is, to a considerable extent, a good criterion for the output capabilities of a certain design. Distortionless reproduction involves the elimination of any grid current that might cause poor voltage regulation from the transformers supplying the grid of the loud speaker tube. The most satisfactory way of insuring zero grid current is to always keep the grid negative. In order that a high negative grid bias can be employed, so that wide swings of grid voltage will not allow the grid to become positive, the tube is designed for a low amplification factor.*

THE UX-120 TUBE

The first loud speaker tube to be designed was the UX-120, which was produced to provide loud speaker output on Radiolas #25 and #28. Work on the design of this tube was started in the Research Laboratory in the fall of 1924. Samples were sent to the R. C. A. in December 1924, and the set engineers rapidly became enthusiastic over its possibilities. Manufacture was started on a small scale in June 1925, the tube being put on sale by the R. C. A. about September 1925.

This tube operated from the same filament voltage as the UX-199 (3.3 volts) having a filament current of 0.135 amperes, about twice that of the 199 tube. It was designed to operate at plate voltages up to 135 at which a negative grid bias of 22½ volts is used, producing 3½ milliamperes plate current.

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* The amplification factor of a tube is a measure of the maximum voltage amplification obtainable from the tube alone. It can be measured by noting the number of volts change in plate voltage required to produce that amount of change in plate current which is produced by a change of, for example, one volt on the grid; the ratio of the plate voltage change to the grid voltage change (each producing the same change in plate current) being the amplification factor. The amplification factor is not appreciably altered by various grid and plate voltages, except that at low plate voltages it may decrease slightly.

The spacing between and size of grid wires, as well as the distance between grid and plate, largely determine the amplification factor of a tube. A tube designed for a low amplification factor has a higher mutual conductance than if it were designed for a high amplification factor so, in order to obtain maximum power output, it is desirable to design a loud speaker tube with a relatively low amplification factor.

In the usual method of estimating distortionless output from a vacuum tube, three assumptions are made:

(1) That the grid is not allowed to draw current, which means that the grid voltage at all times during its swing must be negative.

(2) That the load impedance is adjusted to the optimum value in relation to the plate resistance of the tube. In most cases this means that the loud speaker impedance is about double that of the tube resistance. It must be kept in mind, however, that the impedance of a loud speaker varies widely with the frequency of the signal current supplied to it, so that this load impedance ratio can only be approximated.

(3) That only the straight part of the characteristic curve be employed. This is usually expressed quantitatively by saying that the variation in direct current through the loud speaker between the steady D. C. value and the value when the full output is being obtained, must not be greater than 5%. Another way of expressing this is by saying that the distortion due to second harmonic must not exceed 5%.

On the basis of these criteria the 199 tube with 90 volts on the plate and a negative grid bias of 4½ volts will deliver approximately 7 milliwatts (0.007 watts) into a loud speaker at good quality with a plate current of 2½ milliamperes. The 120 tube at 135 plate volts and 22½ volts negative grid bias will deliver approximately 110 milliwatts, the plate current being 6½ milliamperes. It will be noted that this is an increase in distortionless output of approximately twelve fold while the filament current is only doubled, the plate current being increased about 2½ times and the plate voltage about 50%.

The sale of dry battery sets during the past two years has rapidly decreased so that the demand for the 120 tube is now relatively small.

THE UX-112 TUBE

During 1923 and 1924 the Westinghouse Company was working on the development of an improved general purpose tube which also had better characteristics for loud speaker operation than the 201A tube. In the latter part of 1924 this tube was recommended to the R. C. A. and manufacture was under way in 1925. The 112 tube had a 5 volt, ½ ampere (changed in 1927 to ¼ ampere and called UX-112A) oxide coated filament and, when operated at the maximum recommended plate voltage of 157, gives, at 10½ volts negative grid bias, a distortionless output of 195 milliwatts with 9½ milliamperes plate current. The 201A tube, at its maximum recommended plate voltage of 135, gives, at 9 volts negative grid bias, an output of 55 milliwatts with 3 milliamperes plate current.

THE 210 TUBE

Activity on the 210 tube started in May 1922 by the desire of the R. C. A. for a tube for loud speaker operation that was capable of delivering considerable power. However, interest lagged and it was not until the latter part of 1924 that the tube was planned for use in R. C. A. equipments. Its first use was in connection with the Rice-Kellogg form of dynamic loud speaker which, in 1925, was manufactured under the name of Radiola loud speaker, model 104.

The designation UV-210 was assigned by the R. C. A. on the basis of a transmitting tube and, in the early part of 1924, a quantity of these tubes was supplied to the Navy for transmitting service.

In 1924 this tube was adopted for the General Electric carrier current receiving equipments because of its very long life, about 15,000 hours under conservative operating conditions. A little later this tube was also adopted by theR. C. A. for their trans-oceanic receiving equipments, and it has since been used by them extensively for this purpose.

The 210 tube employs a carbonized thoriated tungsten filament, that is, during the manufacturing process the filament is flashed in a hydro-carbon vapor. The filament consumes $1\frac{1}{4}$ amperes at $7\frac{1}{2}$ volts. The maximum recommended plate voltage is 425 volts which at 35 volts negative grid bias, produces 18 milliamperes plate current, giving 1540 milliwatts (over $1\frac{1}{2}$ watts) undistorted output.

During the early part of 1925 a large demand developed for this tube for use in connection with Radiolas. The large standard base was adopted, the designation UX-210 being assigned in March 1925. It was announced by the R. C. A., September 1, 1925.

THE UX-171 TUBE

The design of the 171 tube was started in the early part of 1925, the object being to provide the greatest possible output at the lowest tube cost.

The 201A construction was followed very closely. The original tube had a thoriated tungsten filament consuming ½ ampere at 5 volts. In the latter part of 1926 the filament was changed to oxide coated, consuming ¼ ampere at 5 volts and called UX-171A.

Of all the loud speaker tubes it will deliver the greatest amount of power per unit of cost. At the maximum recommended plate voltage of 180 and with 40½ volts negative grid bias, the plate current is 20 milliamperes delivering 700 milliwatts undistorted power.

The tube was first adopted for use in the Brunswick phonograph. In October 1925 it was adopted by the R. C. A. but was not advertised and sold to the public until June 1926.

THE UX-250 TUBE

This tube was suggested, advocated and designed by the Westinghouse Company in the summer of 1926. Development continued actively. It was adopted by the R. C. A. in the early part of 1927, announced in February 1928 and made available a short time later.

The filament is oxide coated consuming 1¼ amperes at 7½ volts. At the maximum recommended plate voltage of 450 and, with 84 volts grid bias, the plate current is 55 milliamperes. It will deliver 4.65 watts of undistorted power, four times that of the 210 tube at 425 volts.

A-C TUBES

The idea of operating the filament of a tube by means of alternating current is old. For the past ten years it has been done in the case of large transmitting tubes used in broadcast and radio telephone transmitters. In the latter part of 1925 the #104 loud speaker, developed by the General Electric Company for the R. C. A., utilized a UX-210 tube for direct operation of the speaker, in which the filament of the tube was operated by alternating current.

THE UX-226 TUBE

The initial step in regard to this tube was taken by the engineers of the R. C. A. In September 1926 they requested samples of such a tube from the manufacturing companies, which were submitted in November.

In tubes of this so-called "raw" a-c type, it is important to have the filament voltage at a low value so that the difference of a-c potential from one end of the filament to the other is a minimum. The hum from such a tube arises principally from two sources. One, the voltage difference existing along the filament; in other words, the a-c electro-static field to which the electrons are exposed. The other is the magnetic effect, the effect on the electrons from the variation of the magnetic field set up by the a-c flowing through the filament.

It so happens that these two effects are opposite so that if there is a proper balance between filament voltage and current, the hum will be at a minimum. In the 226 tube the filament has a voltage of 1.5 and draws 1.05 amperes. For this low voltage type of filament the oxide coated is more suitable than the thoriated tungsten filament. With the exception of the filament, this tube is almost indentical to the 201A tube.

In March 1927 the use of the tube was definitely decided upon for new Radiolas for a-c operation. It was found impossible to use them for detectors, which problem was solved by the development of the indirectly heated cathode tube, UY-227. During September 1927 Radiola #17, using the 226 tube in the radio and first audio frequency stages, was advertised.

The 226 tube has a total emission of about 100 milliamperes, about twice that of the 201A. It has a maximum recommended plate voltage of 180 producing $7\frac{1}{2}$ milliamperes at $13\frac{1}{2}$ volts negative grid bias. At 135 volts plate, the maximum recommended for the 201A tube, the 226 tube producing 6 milliamperes as compared with 3 for the 201A tube, both tubes operated with 9 volts negative grid bias, the mutual conductance of the 226 tube is 1100 micromhos as compared with 800 for the 201A tube under these conditions. The amplification factor of the 226 tube is slightly higher than that of the 201A tube, 8.2 compared with 8.0

THE UY-227 TUBE

This tube, structurally, is fundamentally based on U.S. patent 1,459,412, dated June 19, 1923, applied for in April 1915 by

A. McL. Nicholson of the Western Electric Company, although no mention whatever is made in the patent of a-c operation and the inventor probably did not have this in mind. There are twenty-seven claims to this patent which pretty well cover the indirectly heated type of tube. Claim 4 reads:

> " A thermionic translating
> device comprising an insul-
> ating tube, a coating of
> thermionically active mat-
> erial on the outside of said
> tube, and a heating element
> within said tube. "

In December 1922 H. M. Freeman, of the Westinghouse Company, published an article on an a-c type of tube in the Electric Journal. In principle and in certain details the tube described is very similar to the present 227 indirect heater type of tube. It was, however, a double ended tube.

Dr. Hull, of the Research Laboratory, developed a combination of a three element and rectifying tube in one, which was called a "kenopliotron". His paper describing this tube, which was designed for a-c operation, was presented before the Institute of Radio Engineers and published in the Proceedings of the I.R.E. in April 1923. Undoubtedly, if the trend in radio broadcast reception had been of such a nature as to utilize large numbers of one and two tube sets, Dr. Hull's kenopliotron would have been in common use today.

In June 1925 these tubes were first seriously discussed as a possible R.C.A. product. A few months prior to this McCullough, a former employee of the Westinghouse Company, and who was an independent tube manufacturer, advertised an a-c type of double ended tube similar to that described by Freeman.

In July samples of the Freeman type of double ended tube, such as were featured in the McCullough tube and is still featured in the Kellogg tubes, together with samples of Dr. Hull's kenopliotron were submitted to the R. C. A. By October (1925) it was pretty well established that radio sets within the next few years would have give or more tubes, so that the kenopliotron would not seem as applicable as the Freeman type.

In April of the next year (1926) the R.C.A. became interested in the heater type of tube and asked for further samples with cost estimates. In June the designation UX-225 was assigned and in July the R.C.A. placed an order for 1000 samples from each factory of these double ended heater tubes. During November the Westinghouse Company suggested the one end construction with a five pin base. At this time and during the next few months there was considerable discussion as to the relative usefulness of the heater type tube in comparison with the low filament voltage "raw" a-c type.

During 1927, while there was still these differences of opinion, the Marconi-Osram Company in England announced their a-c heater type tube.

During this period the set engineers of the General Electric and

Westinghouse Companies had been working on the design of a set to utilize a-c tubes. At a meeting held in March (1927) a sample set was discussed and it was generally agreed that a satisfactory receiver could be built using low voltage "raw" a-c tubes. This decision appeared to render the heater type of tube unnecessary at that time. It was only a few days later, however, when it was found that this sample receiver did not meet requirements so that the need for the heater type tube was re-introduced.

By April the heater type tube was agreed to for the new Radiola #17 design of receiver, the tube to have a five prong base. At first a five volt heater filament was utilized, the idea being to aid interchangeability with a storage battery tube. Later a change was made to 2½ volts as it allowed a simpler and more rugged construction of the cathode and heater elements. The designation UX-225 was changed with the adoption of the five prong base to AY-225, then for commercial reasons to AY-227 and, at a meeting in April when detailed dimensions of the base were established, the present designation UY-227 was adopted. On May 21st (1927) the UY-227 tube was announced in the New York papers.

The Westinghouse Company suggested in June that the mesh plate be introduced to overcome grid emission difficulties. This was adopted a little later. During the early part of the summer shipments were started to the R.C.A.

In September Radiola #17 was announced in which the UY-227 tube was used for the detector. Difficulties were soon reported in this set due to poor life of the 227 tube caused by opencircuiting of the heater wire. By the end of the year (1927) about half a million of these tubes had been manufactured. They were still giving difficulty due to opening of the heater wire. By May 1928 this difficulty had been practically eliminated.

There had been a great deal of difficulty in finding a proper material for use as the insulator between the heater filament and the cathode electron emitting surface. A material must be used that has a low electrical leakage when red hot, that has no reaction with the tungsten filament heater wire, that is relatively easy to free from gas and that does not deteriorate in high vacuum at high temperature. This problem was solved by the General Electric Company by the use of magnesia.

During the development of the tube, there were encountered many difficulties due to hum from receiving circuits incorporating the tube. Some of these were due to electrical leakage through the insulator, stray electrons from the heater, electromagnetic and electrostatic induction, and a-c in the grid circuit due to the arrangement of the wires in the stem press of the tube. These difficulties were overcome by refinements in design and construction.

Difficulty was also experienced from time to time during the development of the tube from noise as distinct from a-c hum. This was found sometimes to be due to electrical leakage and probable movement of the heater wire. This sort of difficulty has been largely overcome by refinements in design.

Probably one of the greatest difficulties from the manufacturing viewpoint was the difficulty of exhaust in comparison with the filament type of tube. This has been overcome through intensive study in each stage in the process of exhaust and in the use of more power in the high frequency heating of the interior structure of the tube.

The 227 tube is now recommended and used in recent Radiolas for amplification as well as detection. It has a total emission of about 125 milliamperes and an amplification factor of about 9 as compared with about 100 and 8 for the 226 tube. At the 180 volts maximum recommended plate voltage it produces about 5 milliamperes at 13½ volts grid bias as compared with about 7½ milliamperes for the 226 tube. It has a mutual conductance of about 1000 micromhos at 180 plate volts as compared with 1170 for the 226 tube at this plate voltage.

THE HIGH AMPLIFICATION TUBE, UX-240

A tube of the 201-A type but having a high amplification factor, particularly designed for resistance coupled amplification, was first proposed and submitted to the R.C.A. in the summer of 1923. They were not greatly interested in this type of tube although it was finally adopted and the type number assigned in the latter part of 1926. It was announced in February 1927.

It's amplification factor is 30 as compared with 8 for the 201-A tube. The thoriated tungsten filament is the same as in the 201-A tube, being designed for 1/4 ampere at 5 volts. At the maximum recommended B supply voltage of 180 operating through a 250,000 ohm plate resistor, with a negative grid bias of 3 volts, the plate current is 0.2 milliamperes and the mutual conductance is 200 micromhos. The voltage drop through the plate resistor (250,000 ohms times 0.0002 amperes) is 50 volts, so the actual voltage on the plate of the tube under those conditions (180 less 50) is 130 volts.

THE UX-200A DETECTOR TUBE

During the early part of 1922, Dr. E. E. Charlton of the Research Laboratory at Schenectady made tests of tubes as detectors that contained the vapors of an alkali metal. As a final result of this work, a patent was applied for in his name on the combination of a thoriated filament and caesium vapor. Successful sample tubes were built by Dr. Charlton in 1923.

In the fall of 1922 Dr. Langmuir and Dr. Kingdon investigated the phenomena occurring in these tubes and found that the detector action was traceable to the production directly at the surface of the filament, of positive ions by the operation of the filament in the vapor of the alkaline metal. This work resulted in a joint patent issued Nov. 8 - 1927 to Kingdon and Langmuir.

In February 1925 samples were built and tested. They were similar to the 201A tube with the addition of caesium. They were originally developed to replace the erratic gas filled detector tube UV-200, hence the adoption of the number 200A. By June 1925 both the Harrison and Cleveland factories had made small quantities of this tube, samples being submitted to the R.C.A. in July. In October detail improvements were made, principally an increase in the amplification factor, and further samples were submitted to the R.C.A., who a short time later recommended their adoption. Actual manufacture on R.C.A. orders was started about April 1926, the tube being announced in May.

In line with all "soft" detector tubes, the 200-A tube has certain limitations. When receiving a powerful local station, no marked increase in signal strength will be noticed with the 200-A substituted for a 201-A tube in the detector socket of a radio receiving set. With distance reception, however, the 200-A tube will show a marked improvement. A hiss is produced when the tube is first lighted which will continue for one or two minutes or until the tube has warmed up. The tube has always given some trouble due to back-ground noise and a howling disturbance that occasionally happens. It has also given some trouble due to loss of sensitivity from electrical leakage in the stem.

The demand for the tube was not as great as the R.C.A. expected it would be so that production was stopped in 1927, the existing stock being used until the fall of 1928 when production was again started.

The trend during the past year or two in radio receiver design has been toward a detector to handle higher voltages rather than greater sensitivity, so there is every reason to believe that, unless some unforeseen development arises, the 200-A tube will gradually become obsolete.

The thoriated tungsten filament takes 1/4 ampere at 5 volts, the plate current of the tube being 1 1/2 milliamperes at 45 volts with the grid return connected to the negative filament terminal. Under these conditions the mutual conductance is 666 micromhos, about half again as much as that of the 201-A tube at 45 volts. The amplification factor is 20 compared with 8 for the 201-A.

THE UX-222 SCREEN GRID TUBE

The electrostatic capacity between the grid and plate of a three element tube, causes a feed back of energy from the plate output circuit to the grid input circuit of the tube which, under certain circumstances, produces an unstable condition. By placing a screen, a shield through which the electrons can pass, between the grid and plate, the capacity effect between these two elements can be very greatly reduced. If the screen is grounded the electrostatic lines of force from the plate do not reach the grid. If, in addition, the shield is made positive with respect to the filament, some of the space charge limitation is reduced, resulting in a lower impedance. Such a four element tube has advantages over the three element tube, especially in the amplification of radio frequencies where unstable conditions occur. It is for this purpose that the tube is primarily designed.

The screen grid may, however, be used as the controlling grid instead of using the inner grid for this purpose and, if a suitable positive potential be put on the inner grid, the impedance of the tube will be lowered. When using this "space charge grid" connection, the tube has a high amplification factor and a high mutual conductance (without the stability feature however). These are of value in amplifying audio frequency currents where unstable conditions are less apt to occur. In both the "screen grid" and "space charge grid" connections, special circuit conditions are necessary.

In 1919 W. Schottky in Germany published an article on a form of tube in which there was a shield between the grid and plate. However, this tube was not designed for radio frequency use. In the fall of 1923 Dr. Hull and Dr. Williams of the Research Laboratory at Schenectady started their work on the screen grid tube.

An interesting circumstance occurred in 1924 during the development of the tube. The General Electric Company had brought out the Armstrong second harmonic super-heterodyne receiver. This receiver had such high sensitivity that it was possible to obtain satisfactory operation with a loop only one foot in diameter and the first sets were provided with such a loop. Under these conditions there was observed a loud hiss whenever the receiver was tuned to the unmodulated carrier wave of a station, that is, a station which is "on the air" but not broadcasting at the moment.

This hiss was a loud enough noise to be annoying and the Research Laboratory at Schenectady was asked to investigate its cause. Considerable data had been accumulated by the Radio Department of the G.E. Company on the characteristics of this hiss. After discussion with Dr. Langmuir, Dr. Hull, and others in the laboratory, it seemed probable that in this case the limit of amplification had been reached, owing to the fundamental phenomenon that electricity is supposedly composed of finite electrons instead of being a continuous fluid.

In other words, there was being observed a roughness due to the grain size of electricity just as one reaches a limit of magnification of a photograph where the details of the picture are obscured by the graininess of the photographic plate. This phenomenon had been predicted on theoretical grounds by Schottky and was designated by the name "Schrott" (shot effect). Investigation indicated that this was the cause of the hiss.

The hiss depended, as had been predicted, on the magnitude of the plate current of the first tube, on the charge of the electron and, to a slight extent, on the circuit constants. In subsequent receiving sets, a separate oscillator was used so that a much smaller plate current could be employed in the first tube. This reduced the hiss to about one-fifth of the former amount.

In order to make these tests it was necessary to build a high frequency amplifier which would amplify about 100,000 fold in voltage and be sufficiently stable so that different input circuits could be used without changing the amplification. It seemed hopeless to attempt this with three element tubes so special screen tubes were made for the purpose which proved exceedingly reliable.

This work encouraged Drs.Hull and Williams to continue further experimental work on the screen grid tube during 1924 and 1925. In March 1924 the Harrison Works made up the first factory built samples of these tubes. In July 1926 the R.C.A. was given samples, the designation UX-222 being assigned in November 1926. In the latter part of December 1926 a set incorporating these tubes was submitted to the R.C.A. but was neither approved nor recommended. In February 1927 the Cleveland factory started a small but regular production of the tube, the tube being announced by the R.C.A. in October of that year.

The two filament terminals and the plate terminal are connected to their usual prongs on the UX base, the screen surrounding the plate (sometimes called the outer grid) being connected to the grid prong of the base. The inner grid is connected to a cap on top of the bulb.

The theriated tungsten filament consumes 0.132 amperes at 3.3 volts. Operated as a "screen grid" tube with the maximum of 135 volts recommended on the plate, with 45 volts positive potential on the screen and with a negative bias of 1 1/2 volts on the inner (control) grid, the plate current is 1.5 milliamperes, the screen also taking 0.15 milliamperes. Under these conditions the mutual conductance is 350 micromhos and the amplification factor 300.

Operated as a "space charge grid" tube in a resistance coupled audio amplifier with the maximum recommended B supply voltage of 180 connected to the plate of the tube through a resistor of 250,000 ohms, with a negative bias of 1 1/2 volts on the screen (the outer) control grid and with 22 1/2 volts positive on the inner grid, the plate current is 1.5 milliamperes and the inner grid current is 6 milliamperes. The mutual conductance then is 400 micromhos and the amplification factor 60.

RECTIFIER TUBES

When an alternating potential is placed between the filament and plate of a tube, current will only flow through the tube when the plate is positive. Thus a pulsating direct current can be obtained from an alternating source, such as the a-c electric service. By stepping up the a.c. service through a transformer, a high a.c. voltage can be obtained that can be rectified into a pulsating d.c. voltage which, with a suitable filter, will produce a substantially constant d.c. supply of the desired voltage for the plate current of radio receiving tubes.

A two element tube, containing a filament and plate, is the so-called "half wave" rectifier as the negative half of the a.c. current is not rectified, no current flowing from the filament to the plate when the plate is at a negative potential. A "full wave" rectifier can be obtained by having two plates in a tube with two filaments connected in series, one for each plate, connecting the filaments through the filter and d.c. load to a central tap on the transformer secondary coil, one plate being connected to one end of the secondary and the other to the other end of the secondary. Thus when one plate is at a positive potential with respect to the filament during one half of the a.c. cycle, the other plate is negative, current flowing only to the one plate which is positive. During the next half cycle, the polarity of the plates is reversed, current then flowing only to the other plate. By this means pulsating d.c. current is flowing, during both half cycles, in the tube.

Two half wave rectifier tubes can be so connected that one rectifies one half cycle and the other the other half cycle, thus producing a full wave rectifier.

THE UX-213 FULL WAVE RECTIFIER TUBE

Work on this tube was started in the fall of 1923. The first plans were for a tube to deliver only 10 milliamperes at 90 to 100 volts, but during the course of development the demand for voltage and power from these tubes increased rapidly. In December 1923 (which was before the adoption of the UX base) the R.C.A. assigned the designation UV-213 to this full wave rectifier tube.

In March 1924 there was again a demand for further output and a redesign was made, the final design being arrived at during the summer of 1924. The thoriated tungsten filament was rated for 2 amperes at 5 volts which produced a total emission of about 350 milliamperes. During the peak of the a.c. cycle the peak of the pulsating d.c. tube current maybe very high, more than twice the normal d.c. output current, when the tube feeds into a condenser as the first part of the filter system, the usual method. This is largely due to the inrush current charging the condenser. The maximum output current should therefore be much less than the total emission and in this tube it was rated at 65 milliamperes for both plates. The maximum recommended a.c. voltage per plate was 220 (making 440 volts between plates) which produced a pulsating d.c. output voltage of 170 volts at the input of a filter system at the maximum d.c. output current 65 M.A. The filtered d.c. voltage of course was less than this, depending upon the resistance of the filter system.

In December 1924 it did not look as if this rectifier tube, which was called a "Rectron" would find immediate application in Radiola sets, nor was it favored for sale by the R.C.A. However, in February 1925, this attitude changed and samples were submitted to the R.C.A. As late as the summer of 1925 the R.C.A. was not interested, they were favoring the use of dry cell tubes and B batteries, but the UX-213 tube was finally announced by them in September 1925.

As late as March 1926 the sales were very limited. This was largely due to the fact that the Raytheon tube (a neon gas rectifier tube) had been placed on the market ahead of the UX-213 and practically all of the B eliminator manufacturers were incorporating this Raytheon tube in their equipments.

In the UX-213 (and the 280 which superseded it) the plates are connected, one to the plate prong and the other to the ordinarily used grid prong of the UX base. The thoriated tungsten filament is connected to the two ordinarily used filament prongs.

In the fall of 1927 the 213 tube was no longer listed, having been superseded by the 280 tube.

THE UX-280 FULL WAVE RECTIFIER TUBE

In January 1927 the Westinghouse Company started work on a design of higher capacity rectifier tube to supersede the 213 tube, and this new tube was tentatively agreed upon in April, the designation UX-280 being applied in May of that year.

The filament is the oxide coated type, designed for the same amperes and voltage (2 amperes at 5 volts) as that of the thoriated tungsten filament in the 213 tube. The filament emission is over 400 milliamperes, the rated maximum d.c. output current being 125 milliamperes, nearly twice that of the 213 tube. The maximum recommended a.c. voltage per plate is 300 volts (600 volts between plates). This maximum has recently been increased to 350 volts. With 300 volts a.c, the output voltage at maximum output current (125 M.A.) as applied to the input of the filter, is 260 volts d.c.

In order to assist in the dissipation of heat from the plates, they are coated with carbon. The tube was announced by the R.C.A. on May 22, 1927.

THE 216 HALF WAVE RECTIFIER TUBE

The first half wave rectifier tube, known as UV-216, was put on sale in 1921. It had a pure tungsten filament designed for 2.35 amperes at 7 1/2 volts. The tube was primarily intended for the plate current supply for the 5 watt transmitting tube, producing about 50 milliamperes at about 350 volts, the filament emission being about 100 milliamperes. The designed a.c. input voltage was 550 volts.

In the fall of 1924 work was started on the design of a half wave rectifier tube utilizing a thoriated tungsten filament. In

December the designation 216A was applied by the R.C.A. to this tube. This designation was later changed to 216B because the designation 216A was utilized by the Western Electric Company in a tube they merchandised for loud speaker use.

By August 1925 the tube was in production and was announced and put on sale by the R.C.A. about September 1925. In the fall of that year, the tube was in use in connection with the #104 Radiola loud speaker and the Uni-rectron, the latter a B battery eliminator which also contained a 210 tube as a last stage high power audio output tube.

The thoriated tungsten filament of the UX-216B rectifier tube was designed for 1 1/4 amperes at 7 1/2 volts. The filament emission was about 350 milliamperes. The maximum recommended a.c. plate voltage was 550 volts, the maximum d.c. output current 65 milliamperes at which d.c. current and a.c. plate volts produced 470 pulsating d.c. voltage at the input of the filter.

This tube was superseded by the UX-281 rectifier tube due to filament breakage and the need for greater output on new equippments, the 216-B tube being no longer listed by the R.C.A. in the fall of 1927.

THE UX-281 HALF WAVE RECTIFIER TUBE

In the early part of 1927 work on the development of this tube was started. In April of that year definite plans had been completed and the designation UX-281 applied in May.

The tube has an oxide coated type of filament of the same current and voltage (1 1/4 ampere at 7 1/2 volts) as the 216B tube it superseded. The filament emission is about 600 milliamperes. The maximum a.c. plate voltage is 700, the maximum d.c. output current is 85 milliamperes at which 620 d.c. volts are produced at the filter input.

In half wave rectifier tubes the normal grid prong is unused.

UX-874 VOLTAGE REGULATOR TUBE

It has been known for many years that a glow discharge has approximately a constant voltage drop over quite a wide range of current. In the latter part of 1924, Dr. E. E. Charlton made some sample glow tubes containing two elements, an anode and a cathode operating in a low pressure of neon gas. Current passes from one element to the other by ionization of the gas, the voltage drop remaining approximately constant at about 90 volts, the variation in voltage being but about plus and minus 1 1/2 volts with 20 milliamperes variation in current above and below the normal 30 milliamperes (from 10 to 50 m.a.). The normal voltage may vary in individual tubes from a little more than 80 to a little less than 100 volts.

The intended use of the glow tube is to maintain an approximately constant 90 volts across the 90 volt tap of a B eliminator. To start the glow about 125 volts d.c. is required. Sufficient resistance must be used in series with the tube to limit the current to 50 milliamperes.

Work on the tube in the factories was started in March 1925 and was along the lines of neon gas with caesium or potassium as a getter. In the fall of 1925 the Westinghouse factory at Bloomfield found that the use of another getter, such as misch-metal (a mixture of the rare earth metals) and argon, gave nearly equivalent characteristics and later, for certain manufacturing and performance reasons, the production was changed over (the G.E. factories in March 1927) to this type.

Use of this tube in radio equipments was started in the fall of 1925 and considerable difficulty was encountered for a few months in meeting the requirements in Radiola receivers. By the early part of 1926, however, the demand had fallen off to a considerable extent as far as new equipments were concerned.

In the 1927 Radiolas, this tube was not employed and it has been used to a lesser and lesser extent since then. It is still listed by the R.C.A. but is sold only in small quantities.

Looking at the bottom of the UX base, with the pin on the side of the base pointing upward, the negative element (the cylinder) is connected to the left hand filament prong and the positive element (the wire) is connected to the upper right hand prong (the normal grid prong). The other two prongs (the other filament prong and the normal plate prong) are connected together in the base and this short circuited connection may be used as a line switch in the transformer primary. With this connection, the eliminator cannot be turned on until the tube is inserted in the socket nor can tubes be interchanged in such a way as to damage either the equipment or the tubes themselves. Two 874 tubes may be placed in series to obtain 180 volt regulation, a center tap between the tubes then providing 90 volts.

CURRENT REGULATOR (BALLAST) TUBES, UV-876 and UV-886

These tubes were designed to insure constant input to power operated radio receivers despite fluctuations in the service line voltage. They were especially built for the #104 Radiola loud speaker, the UV-876 used when the speaker was operated from a sixty cycle supply and the UV-886 when operated from a forty cycle supply. They have not been used in any of the more modern Radiola sets.

These tubes contain an iron wire filament operating in hydrogen gas. Iron operated at about a certain temperature has a very steep resistance characteristic, that is, a slight increase in current through the filament producing a slight increase in temperature, causes a great increase in resistance, and vice-versa. This principle was used more than twenty years ago in the Nernst lamp ballast. Thus, with the normal current of 1.7 amperes flowing through the iron wire filament in the UV-876 tube, a voltage drop of 50 volts is produced across the filament. If the voltage be increase 10 volts, the current will increase but 0.03 amperes and vice versa.

The UV-876 tube is placed in series with the primary of a transformer designed for 1.7 amperes current in the primary coil and consumes normally 50 volts of the 115 volt lighting circuit. If the same transformer is used on 40 cycles (instead of 60 cycles) the primary current would be 2.05 amperes for which the UV-886 is designed. On a lighting circuit normally 115 volts, the voltage on the primary of the transformer is 65 volts, (115 less 50). If the lighting circuit voltage drops or rises 10 volts, the voltage across the ballast tube will change accordingly and voltage across the primary coil of the transformer will remain practically constant at 65 volts.

The tube requires several minutes to heat up, the voltage drop increasing rapidly for the first three minutes and then slowly up to about ten minutes, by which time the tube has reached its final temperature. During this interval the voltages on the tubes in the radio receiving set will be slightly high but will not exceed safe values.

The tube, is filled with hydrogen gas and if air leaks into the bulb a gas mixture may be formed which, if ignited by the hot iron wire filament, may cause a violent explosion. Suitable precautions must always be taken by enclosing the tube in a metal housing properly ventilated.

The base is the ordinary unskirted mogul screw as used on the larger sizes of MAZDA lamps.

PROTECTIVE TUBE UV-877

This has a tungsten filament operating in vacuum in a bulb fitted with a double contact bayonet candelabra base. Tungsten has a positive resistance characteristic, a slight increase in current producing a considerable increase in resistance. The tube is designed for use in radio receiving sets to limit the current drawn from the B battery in case of short circuit. The tube was put on the market in 1925 but as it was not used to a great extent it was removed by the R.C.A. from their price lists in 1926.

The tube is connected between the first and second blocks of 45 volt B batteries. The shell of the base connects with the center point of the filament and with the 45 volt tap on the radio set. With a current of 20 milliamperes flowing through the filament, the voltage drop will be 2 1/2 volts across each half of the filament or 5 volts across the entire filament. With a current of 90 milliamperes the voltage drop will be 45 and 90 volts respectively, thus preventing the current rising to dangerous values in case of short circuits in the set, especially protecting the filaments of tubes from burn out when they are accidentally connected to the Bbattery circuit in the set.

The tube is not suitable for use in sets in which the total B battery current consumption is more than 25 milliamperes.

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